Appendix F

SYSTDG Statistical Evaluation
April – August 2014

February 2015

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Section 1 Introduction

SYSTDG (System Total Dissolved Gas) is a decision support spreadsheet model used to estimate total dissolved gas (TDG) percent of saturation and pressures resulting from mainstem dam operations on the Columbia, Snake, and Clearwater rivers. SYSTDG contains equations that calculate the travel time for the TDG levels produced at the upstream tailwater to arrive at the next downstream forebay. It uses a hydrological routing procedure that involves surface aeration exchange with dispersion to calculate/estimate what the next downstream forebay %TDG level will be. A statistical evaluation of the differences between model estimates and observed %TDG (predictive errors) for the forebay and tailwater gauges was performed comparing hourly observed and calculated TDG levels from the SYSTDG model using actual meteorologic data. This evaluation includes Bonneville, The Dalles, John Day, McNary, Ice Harbor, Lower Monumental, Little Goose, Lower Granite, Dworshak, Chief Joseph, and Grand Coulee dams. A review of project operations and the resultant TDG levels was conducted for the 2014 fish passage season from April 1 through August 31.

The purposes of this statistical evaluation of SYSTDG include:

1. Quantify the annual predictive error of SYSTDG estimates and discuss the causes for high standard deviations (SD) of predictive errors.
2. Quantify the amount of improvement in the model performance the betterments produced in terms of standard deviation per gauge.
3. Provide the SYSTDG modelers with an understanding of the long-term trend in predictive error for each TDG monitoring gauge for more effective use of the model when reviewing and setting daily spill caps.
4. Identify the locations and recommendations for continued development that will improve modeling accuracy Address the 2010/2014 Supplemental Biological Opinion, RPA 15 requirements associated with SYSTDG, which are:
   - Continued development and use of SYSTDG model for estimating TDG production to assist in real-time decision making
   - Continued development of fish passage strategies with less production of TDG (e.g., removable spillway weirs) and
   - Update the SYSTDG model to reflect modifications to spillways or spill operations

Section 2 Statistical Analysis and Results

In order to generate the statistics on the predictive errors, SYSTDG simulations were calculated independently for each dam and river reach from April 1 through August 31. The predictive error was calculated by subtracting the calculated TDG level from the observed value ($TDG_{error} = TDG_{obs} - TDG_{cal}$). The difference between the hourly observed and calculated %TDG was the definition used for the predictive error where negative errors reflect over-estimation of observed conditions and positive errors reflect an under-estimation of observed conditions.

The greatest number of hours that could be included in this analysis per project is 3,671 hours if usable data was available for all hours from April 1 through August 31. But in most cases, the number of observed hours was lower than 3,671 because not all days or hours met the criteria of the modeling conditions and operational ranges. In order to assess how well the model performs, it is necessary to use the hours/days when the operational conditions are typical or "normal". The hours associated with operational conditions that were outside of normal conditions and were therefore excluded from this analysis, include:

1. The hours with no spill are not counted for the tailwater gauge.
2. The first three hours of spill while the model is calibrating. Thus tailwater gauge predictive errors were analyzed only for spill operations longer than 3 hours in order to exclude transient TDG observations.
3. The hours when special spill operations were conducted are not included for tailwater gauges. These special spill operations that are not established in the FOP include speed-no-load, doble testing or operating a unit outside of its 1% efficiency limits.
4. The hours when the TDG gauge was malfunctioning were not included for either a forebay or tailwater gauge.
5. The hours when there was a transition between outlet tubes verses drumgate spill at Grand Coulee Dam.
6. Any hours associated with project operations when the applicable spill pattern does not cover the flows occurring in the river.

2.1 The Ten-Year Statistical Analyses Results, 2005-2014

A ten-year (2005-2014) system-wide summary of the statistical analyses of the SYSTDG model was prepared in order to evaluate how the 2014 system-wide statistical analysis compares with the previous years. The ten-year summary results in %TDG are shown in Tables F-1 and F-2 and in mm Hg pressure in Tables F-3 and F-4.

Table F-1
2005-2014 Average Statistical Summary of the Predictive Errors Of the Observed and Calculated TDG At Forebay TDG Gauges (%TDG) for April through August

Fixed Monitoring Stations		LGSA	LMNA	IHRA	WEL*	CHJ*	MCNA	JDY	TDA	BON	CWMW
Number of Obs		3564	3579	3575	3055	2733	3584	3471	3509	3548	3519
Average		0.4	0.0	0.0	0.0	0.5	0.1	0.6	-0.2	0.3	0.4
Standard Deviation		2.0	1.7	1.4	1.1	1.0	1.7	1.5	1.2	1.0	1.2
Maximum		6.6	4.5	4.0	5.7	6.0	6.0	6.0	4.2	4.8	9.3
Minimum		-6.2	-4.9	-5.0	-3.4	-4.5	-5.2	-3.9	-4.5	-2.9	-2.8
TDG Predictive Error in % TDG	Percentile										
	5%	-3.3	-2.9	-2.4	-1.6	-1.1	-2.6	-1.6	-2.2	-1.3	-1.3
	10%	-2.2	-2.2	-1.8	-1.2	-0.7	-2.0	-1.2	-1.7	-0.9	-1.0
	25%	-0.7	-1.1	-0.8	-0.6	-0.1	-1.1	-0.5	-0.9	-0.4	-0.5
	50%	0.6	0.1	0.1	-0.1	0.6	0.0	0.5	-0.2	0.3	0.2
	75%	1.6	1.2	1.0	0.5	1.1	1.2	1.6	0.6	1.0	1.1
	90%	2.7	2.1	1.7	1.1	1.5	2.2	2.6	1.3	1.6	2.0
	95%	3.4	2.6	2.1	1.8	2.0	2.9	3.3	1.9	2.0	2.6

* WEL and CHJ includes only 2010-2014

Table F-2
2005-2014 Average Statistical Summary of the Predictive Errors Of the Observed and Calculated TDG At Tailwater TDG Gauges (%TDG) for April through August

Fixed Monitoring Stations		DWQI	LGNW	LGSW	LMNW	IDSW	GCGW*	CHQW*	MCPW	JHAW	TDDO	CCIW	WRNO
Number of Obs		1254	3086	2888	2908	2785	645	1166	2697	2275	2932	2806	2367
Average		-0.3	-0.7	0.0	0.0	-0.3	-1.6	-0.4	0.7	-0.3	-0.2	-0.2	0.1
Standard Deviation		1.3	2.3	1.6	2.0	1.2	2.2	1.4	1.5	1.5	1.1	1.3	1.4
Maximum		7.5	8.0	9.8	9.2	4.5	5.7	6.7	11.4	5.6	4.4	5.2	5.3
Minimum		-7.9	-9.3	-7.4	-8.5	-6.1	-9.6	-5.2	-4.0	-5.8	-5.3	-6.4	-5.3
TDG Predictive Error in % TDG	Percentile												
	5%	-2.1	-4.4	-2.7	-3.2	-2.3	-5.3	-2.6	-1.4	-2.7	-1.9	-2.7	-1.9
	10%	-1.7	-3.6	-1.9	-2.4	-1.9	-4.2	-2.1	-0.8	-2.1	-1.4	-1.8	-1.4
	25%	-1.0	-1.9	-1.0	-1.2	-1.1	-2.7	-1.2	-0.4	-1.3	-0.8	-0.8	-0.8
	50%	-0.3	-0.6	-0.1	0.0	-0.2	-1.4	-0.4	0.6	-0.4	0.0	-0.1	0.0
	75%	0.4	0.6	0.9	1.3	0.5	-0.3	0.5	1.6	0.8	0.6	0.4	0.8
	90%	1.0	1.9	1.7	2.3	1.2	0.6	1.4	2.5	1.7	1.2	1.0	1.8
	95%	1.4	2.7	2.3	2.8	1.7	1.3	1.8	3.0	2.2	1.6	1.4	2.5

* GCGW and CHQW includes only 2010-2014

Table F-3
2005-2014 Average Statistical Summary of the Predictive Errors
Of the Observed and Calculated TDG
At Forebay TDG Gauges (mm Hg Pressure) for April through August

Fixed Monitoring		LGSA	LMNA	IHRA	WEL	CHJ	MCNA	JDY	TDA	BON	CWMW
Number of Obs		3564	3579	3575	2940	2828	3584	3471	3509	3548	3515
Average		-0.1	-2.7	-2.1	-1.6	0.7	-2.0	2.3	-1.2	2.5	2.7
Standard Deviation		15.2	12.5	10.3	7.5	8.6	12.3	11.6	9.4	7.9	9.2
Maximum		50.9	49.6	29.3	37.6	44.1	41.6	44.9	39.1	36.8	43.9
Minimum		-51.3	-39.1	-39.6	-24.8	-37.5	-40.2	-27.7	-34.0	-21.8	-21.7
TDG Predictive Error in mm Hg	Percentile										
	5%	-28.6	-23.9	-20.1	-11.9	-13.8	-20.8	-14.8	-16.4	-9.8	-9.8
	10%	-20.3	-19.2	-15.4	-9.3	-10.4	-16.7	-11.4	-13.1	-7.2	-7.4
	25%	-8.2	-10.8	-8.6	-5.8	-4.7	-10.3	-6.2	-7.2	-2.9	-3.8
	50%	1.2	-2.1	-1.4	-2.3	1.1	-2.5	1.4	-1.1	2.3	1.1
	75%	9.5	6.1	5.1	1.8	6.6	5.6	9.7	4.5	7.5	8.1
	90%	17.3	12.0	10.3	5.8	10.4	13.4	17.4	10.2	12.2	15.2
	95%	23.1	16.1	13.2	10.4	13.3	18.7	22.4	14.2	15.0	20.0

* WEL and CHJ includes only 2010-2014

Table F-4
2005-2014 Average Statistical Summary of the Predictive Errors
Of the Observed and Calculated TDG
At Tailwater TDG Gauges (mm Hg Pressure) for April through August

Fixed Monitoring Stations		DWQI	LGNW	LGSW	LMNW	IDSW	GCGW*	CHQW*	MCPW	JHAW	TDDO	CCIW	WRNO
Number of Obs		1146	3086	2888	2906	2873	643	1166	2697	2275	2932	2835	2367
Average		-6.1	-7.9	0.7	-0.2	-2.2	-11.7	-2.9	5.1	-1.9	0.6	0.2	2.8
Standard Deviation		10.6	17.3	11.9	14.3	9.2	15.6	10.5	11.0	11.2	8.3	9.8	10.2
Maximum		51.9	55.5	73.0	55.9	34.0	41.6	49.7	85.8	38.1	35.0	41.2	42.0
Minimum		-62.0	-72.8	-55.7	-63.2	-47.3	-70.5	-38.4	-31.0	-43.6	-38.2	-46.9	-38.2
TDG Predictive Error in mmHg	Percentile												
	5%	-19.5	-35.8	-17.4	-23.9	-17.6	-38.8	-20.6	-10.6	-19.2	-11.8	-17.3	-12.2
	10%	-17.4	-30.1	-12.3	-18.0	-14.2	-30.8	-16.2	-7.3	-15.5	-8.3	-11.9	-8.7
	25%	-12.4	-17.1	-6.3	-9.0	-8.0	-19.9	-8.6	-2.7	-9.8	-3.5	-3.6	-3.8
	50%	-6.3	-7.4	0.5	0.2	-1.6	-10.2	-2.9	4.3	-2.6	1.9	1.3	1.7
	75%	0.8	2.4	7.7	9.4	3.6	-2.5	3.4	12.2	6.0	6.5	5.4	8.5
	90%	5.9	11.9	14.5	16.8	8.7	4.4	10.2	18.7	12.7	10.8	9.5	15.4
	95%	8.3	17.1	18.9	21.0	12.5	9.5	13.3	22.6	16.6	13.8	12.2	20.7

* GCGW and CHQW includes only 2010-2014

2.2 The Ten-Year Range Standard Deviation, 2005-2014

The ten-year system-wide average SD was 1.5%. It is typically considered that a SD for a range of 5% or less is an indicator of an acceptable model performance. The range describes the spread of the data set and is determined by subtracting the minimum data value from the maximum. Since SYSTDG is designed to model spill operations from April through August in all water years, the maximum and minimum %TDG is taken from what occurred during any type of water year during those months. Therefore, the %TDG data can vary between 95% to 145%. This is a data set range of 50%TDG. Using

this number for the range and the ten-year system-wide average SD of 1.5%, the range SD can be calculated using the following equation:

$$\text{SD for the range} = (1.5/50)(100) = 3.0\%$$

A 3.0% SD for a range is considered very acceptable model performance. A 5% range SD is equivalent to a 2.5% SD for an individual gauge. A review of Table F-1 and F-2 shows that all the TDG gauges in SYSTDG have range SD below 5%. These results show that the SYSTDG model is well developed and accurately estimates the TDG levels at the forebay and tailwater gauges in the dams on the Columbia River, lower Snake River and the Clearwater River. These results also suggest that the Corps has achieved the RPA 15 SYSTDG requirements.

There are TDG gauges that consistently have higher than average SDs but within the acceptable SD and they are as follows:

- Lower Granite tailwater gauge has a SD of 2.3%, which is the highest SD in the system-wide arrangement (see Table F-2). This gauge shows a consistent trend of having a higher SD than the ten-year system-wide SD and it is believed to be associated with the TDG production equations in the model. These equations could potentially be improved.
- The Little Goose forebay and tailwater gauges' ten-year SDs are 2.0% and 1.6% respectively (see Table F-2). These higher than average SDs are attributed to the Lower Granite Dam TDG production equations issues. It is believed that more TDG is being produced at Lower Granite Dam than is accounted for in Lower Granite Dam TDG production equations and this results in higher than estimated TDG levels at the Little Goose forebay. Once the Lower Granite Dam TDG production equations are improved, this should also improve the Little Goose forebay and tailwater gauges' SD.
- The Lower Monumental tailwater gauge's ten-year SD is 2.0% (see Table F-2). This higher than average SD is attributed to the TDG production equations during high flows. Large changes in TDG production are observed with small changes in spill rate. These equations could potentially be improved.
- The McNary forebay gauge's ten-year SD is 1.7% (see Table F-2). This higher than average SD is attributed to the fact that the Pasco gauge is the boundary for McNary forebay gauge, and if the observed data from Pasco gauge is of poor quality, then predictive error will be elevated. The Pasco gauge experiences fouling caused by algae growths this can result in data quality issues.

2.3 Individual Gauge Standard Deviations from 2005-2014

SYSTDG statistical analyses have been performed for 10 years spanning from 2005 to 2014 and Tables F-5 and F-6 provide the individual gauges' annual SDs.

Table F-5
2005-2014 Standard Deviations
At Forebay TDG Gauges (%TDG) for April through August

Year	LGSA	LMNA	IHRA	WEL*	CHJ*	MCNA	JDY	TDA	BON	CWMW
2005	2.1	1.1	1.2	---	---	1.9	1.1	1.1	0.9	1.4
2006	2.5	2.6	1.3	---	---	1.5	1.2	1.0	0.9	0.9
2007	2.4	2.0	1.3	---	---	1.3	1.4	1.0	1.0	1.3
2008	2.2	1.7	1.3	---	---	1.5	1.7	1.6	1.0	1.4
2009	1.8	1.6	1.2	---	---	1.5	1.3	1.2	0.9	1.8
2010	1.7	1.7	1.5	1.4	1.1	2.1	1.2	1.5	0.9	1.2
2011	1.7	1.7	1.7	0.8	1.2	1.7	1.7	1.2	0.9	0.8
2012	2.3	1.4	1.2	0.6	1.1	1.6	2.2	1.4	1.3	1.0
2013	1.6	1.9	1.4	1.2	0.9	2.2	1.8	1.1	1.2	1.0
2014	1.5	1.3	1.4	1.6	0.8	1.8	1.9	1.3	1.5	1.5
2005-2010	**2.1**	**1.8**	**1.3**	**1.4**	**1.1**	**1.6**	**1.3**	**1.2**	**0.9**	**1.3**
2011-2014	**1.8**	**1.6**	**1.4**	**1.1**	**1.0**	**1.8**	**1.9**	**1.2**	**1.2**	**1.1**

* Wells and Chief Joseph forebay gauges were not included in the analysis. N/A denotes that the gauges was not installed yet.

Table F-6
2005-2014 Standard Deviations
At Tailwater TDG Gauges (%TDG) for April through August

Year	DWQI	LGNW	LGSW	LMNW	IDSW	GCGW*	CHQW*	MCPW	JHAW	TDDO	CCIW	WRNO
2005	1.5	**4.9**	1.6	1.7	1.4	---	---	1.5	1.4	1.0	1.0	2.0
2006	1.7	2.1	1.8	**3.0**	1.4	---	---	1.3	1.4	0.9	1.9	1.5
2007	0.7	1.8	2.2	1.9	1.7	---	---	2.4	1.5	1.8	1.2	1.1
2008	2.0	1.5	1.3	2.0	0.9	---	---	1.0	1.6	1.3	2.4	1.3
2009	1.7	1.3	1.1	1.7	1.0	---	---	1.1	1.9	1.0	0.8	0.9
2010	0.6	2.3	1.1	1.5	1.1	**4.1**	1.5	1.8	1.7	0.9	1.0	1.2
2011	1.3	2.1	2.1	1.7	0.9	1.7	1.4	1.8	1.9	1.1	1.5	1.0
2012	1.0	2.2	1.7	2.4	1.0	1.4	1.2	1.2	1.3	1.2	1.4	1.2
2013	0.8	2.8	1.6	2.3	1.5	1.5	1.3	1.4	1.2	1.1	0.9	1.8
2014	2.0	1.9	1.6	1.6	1.3	2.1	1.6	1.1	1.2	1.1	0.8	1.5
2005-2010	**1.4**	**2.3**	**1.5**	**2.0**	**1.3**	**4.1**	**1.5**	**1.5**	**1.6**	**1.1**	**1.4**	**1.3**
2011-2014	**1.3**	**2.2**	**1.7**	**2.0**	**1.2**	**1.7**	**1.4**	**1.4**	**1.4**	**1.1**	**1.2**	**1.4**

* Grand Coulee and Chief Joseph tailwater gauges were not included in the analysis.

2.4 Review of The Effectiveness of Model Improvements

A review of the individual gauges' annual SDs in Tables F-5 and F-6 highlights the effectiveness of the model betterment that occurred from 2005 to 2014. The SD for certain time periods are not shown on Table F-5 and F-6 and must be calculated by hand because the significant period for each gauge varies depending on when the modification to the exchange equations occurred. There were five improvements to the model that resulted in lower SDs and the following is a discussion of them:

Grand Coulee Tailwater (GCGW) – As Table F-5 shows, GCGW had a SD of 4.1% in 2010, which was considered high. As a result, the TDG production equation was modified for the 2011 spill season based on the 2010 spill data. The modified equations resulted in a 2.4%

improvement (to a SD of 1.7%) in the 2011-2014 period SD. For more information on this improvement, see the 2010 Statistical Analysis of SYSTDG (Appendix G).

Lower Granite Tailwater (LGNW) - As Table F-5 shows, LGNW had an average SD of 3.5% for the 2005 period, which was considered high. As a result, the TDG production equation was modified for the 2006 spill season. The modified equations resulted in a 1.5% reduction in the SD (to a SD of 2.0%) for the 2006-2014 period. For more information on this improvement, see the 2005 Statistical Analysis of SYSTDG (Appendix G).

Little Goose Forebay (LGSA) – The modification of the Lower Granite tailwater gauge TDG production equation in 2005 resulted in a slight (0.1%) reduction in the SD for the 2006-2014 period.

Lower Monumental Tailwater (LMNW) - LMNW had an average SD of 2.3% for the 2005-2008 period, with a SD of 3.0% in 2006, which was considered high. As a result, the TDG production equation was modified for the 2009 spill season. The modified equations resulted in a 0.4% reduction in the SD (to a SD of 1.9% for the 2009-2014 period). For more information on this improvement, see the 2009 Statistical Analysis of SYSTDG (Appendix G).

McNary Tailwater (MCPW) - MCPW had an average SD of 1.5% for the 2005-2011 period, which was considered good. A SD of 1.8% in both 2010 and 2011 at the MCPW gauge prompted a modification of the TDG production equation for the 2012 spill season. The modified equations resulted in a 0.3% reduction in the SD for the 2012-2014 period. For more information on this improvement, see the 2011 Statistical Analysis of SYSTDG (Appendix G).

Dworshak Tailwater (DWQI) – Estimating the TDG production from Dworshak Dam has unique difficulties. Dworshak Dam is the beginning of the model, so it is necessary to have the incoming TDG levels entered as boundary conditions, but there is no forebay gauge to provide this data. As a result, the SYSTDG modeler must estimate what the incoming TDG levels are since SYSTDG does not contain an expression for estimating the forebay or powerhouse TDG levels. The estimation of TDG levels in the Dworshak Dam tailwater requires the estimation of TDG levels in powerhouse flows. The background TDG levels associated with powerhouse flows during spillway/RO flows were interpolated from TDG observations during capacity powerhouse flows with no spill. This situation provides the SYSTDG developer an opportunity to work on possible improvements.

As Table F-5 shows, DWQI had an average SD of 1.4% for the 2005-2011 period, which was considered good. The TDG production equation was modified for the 2012 spill season based on the 2009 through 2011 data. The modified equations resulted in a 0.1% reduction in the SD for the 2012-2014 period. For more information on this change, see the 2011 Statistical Analysis of SYSTDG (Appendix G).

2.5 TDG Gauges that SDs Became Worse

The installation of The Dalles spillwall was completed before April 2010 and it appears to have resulted in a 0.3% increase in the SD for the Bonneville forebay TDG gauge. This may be caused by the spillwall directing the flow to fewer bays and deeper waters promoting a concentrate TDG level downstream and preventing degassing in the shallow reach immediately below the dam. From 2005-2010, the Bonneville forebay SD was 0.9% SD and from 2011 to 2014, the SD was 1.2%, which is still well below the ten-year system-wide SD. Data was collected in 2010 to assess the impacts of the spillwall on the TDG levels, but there were no funds to complete the evaluation of the data.

The McNary forebay SD increase 0.4% during the 2010-2014 period and the cause for this increase is not yet understood.

2.6 The 2014 Statistical Analysis Results

The 2014 SYSTDG system-wide statistical analysis results in %TDG are shown in Tables F-7 and F-8 and in mm Hg pressure in Tables F-9 and F-10. This analysis of the predictive errors for the gauges includes average, minimum, maximum, SD, and the predictive error associated with the following percentiles: 5, 10, 25, 50, 75, 90, and 95%.

Table F-7
2014 Average Statistical Summary of the Predictive Errors
Of the Observed and Calculated TDG
At Forebay TDG Gauges (%TDG) for April through August

Fixed Monitoring		LGSA	LMNA	IHRA	WEL	CHJ	MCNA	JDY	TDA	BON	CWMW
Number of Obs		3525	3436	3672	3230	1753	3672	3453	3452	3660	3435
Average		2.9	2.5	2.1	1.6	1.2	2.1	3.2	2.5	2.3	2.4
Standard Deviation		1.5	1.3	1.4	1.6	0.8	1.8	1.9	1.3	1.5	1.5
Maximum		6.8	5.3	5.5	8.7	5.5	6.9	8.5	5.9	7.2	8.1
Minimum		-2.1	-1.6	-3.0	-1.0	-6.0	-3.5	-1.4	-1.2	-1.3	-1.1
TDG Predictive Error in % TDG	Percentile										
	5%	-0.3	0.0	-0.1	0.0	-0.1	-1.2	0.1	0.5	-0.1	0.1
	10%	0.6	0.5	0.3	0.3	0.2	-0.4	0.9	0.9	0.4	0.6
	25%	2.2	1.9	1.1	0.7	0.7	1.1	1.7	1.6	1.2	1.4
	50%	3.1	2.7	1.9	1.2	1.2	2.2	3.1	2.4	2.3	2.3
	75%	3.8	3.3	3.1	2.1	1.6	3.3	4.8	3.3	3.2	3.4
	90%	4.6	3.9	4.1	3.2	1.9	4.3	5.7	4.1	4.2	4.3
	95%	5.1	4.2	4.5	4.9	2.2	4.9	6.3	4.7	4.7	4.8

Note: Predictive error is the observed minus calculated %TDG where negative values reflect an over-estimation and positive values reflect an under-estimation.

Table F-8
2014 Average Statistical Summary of the Predictive Errors Of the Observed and Calculated TDG At Tailwater TDG Gauges (%TDG)

Fixed Monitoring Stations		DWQI	LGNW	LGSW	LMNW	IDSW	GCGW	CHQW	MCPW	JHAW	TDDO	CCIW	WRNO
Number of Obs		1582.0	3466	3525	3436	3672	666	1753	3672	2921	3452	3660	3660
Average		-1.1	-1.0	-0.5	0.3	0.3	-1.7	0.2	1.0	0.4	1.9	0.0	2.3
Standard Deviation		2.0	1.9	1.6	1.6	1.3	2.1	1.6	1.1	1.2	1.1	0.8	1.5
Maximum		31.5	10.4	7.0	7.0	4.8	4.1	8.3	12.9	5.3	8.8	7.1	8.0
Minimum		-8.6	-8.6	-6.2	-6.6	-12.3	-9.3	-6.0	-3.2	-4.3	-1.6	-5.6	-2.4
TDG Predictive Error in % TDG	Percentile												
	5%	-2.4	-5.1	-5.1	-2.6	-1.6	-6.9	-2.3	-0.6	-1.8	0.3	-1.1	-0.1
	10%	-2.1	-3.8	-3.8	-1.9	-1.1	-4.5	-1.8	-0.3	-1.2	0.6	-0.8	0.4
	25%	-1.7	-1.6	-1.6	-0.5	-0.4	-2.3	-0.9	0.2	-0.4	1.2	-0.5	1.2
	50%	-1.2	-0.8	-0.8	0.6	0.2	-1.4	0.2	0.9	0.5	1.9	0.0	2.2
	75%	-0.8	0.0	0.0	1.2	0.9	-0.3	1.4	1.6	1.2	2.6	0.4	3.3
	90%	-0.2	0.8	0.8	1.9	1.8	0.2	2.1	2.4	1.9	3.2	1.2	4.4
	95%	0.3	1.5	1.5	2.6	2.5	0.5	2.4	2.9	2.2	3.5	1.5	4.9

Note: Predictive error is the observed minus calculated %TDG where negative values reflect an over-estimation and positive values reflect an under-estimation.

Table F-9
2014 Average Statistical Summary of the Predictive Errors Of the Observed and Calculated TDG At Forebay TDG Gauges (mm Hg Pressure)

Fixed Monitoring Stations		LGSA	LMNA	IHRA	WEL	CHJ	MCNA	JDY	TDA	BON	CWMW
Number of Obs		3525	3436	3672	3230	1753	3672	3453	3452	3660	3435
Average		18.9	16.2	12.9	12.0	5.0	13.7	21.6	18.6	17.1	18.1
Standard Deviation		11.2	9.4	10.6	11.7	5.8	13.4	14.2	9.6	11.3	11.2
Maximum		48.1	36.6	38.9	63.7	36.7	49.6	61.0	44.6	55.1	62.4
Minimum		-17.8	-14.7	-25.0	-7.2	-47.5	-28.7	-12.8	-9.1	-10.1	-8.4
TDG Predictive Error in % TDG	Percentile										
	5%	-4.9	-2.3	-3.6	-0.2	-4.2	-10.8	-1.6	4.0	-0.7	0.7
	10%	2.1	1.1	0.0	2.0	-2.1	-5.0	4.8	7.0	2.8	4.3
	25%	14.1	11.6	5.4	5.2	1.6	6.5	10.1	11.7	8.9	10.3
	50%	20.3	17.9	11.8	8.9	5.2	14.2	20.6	18.1	17.3	17.4
	75%	26.1	22.8	20.4	15.3	8.3	22.8	33.4	25.2	24.6	25.6
	90%	31.5	26.5	28.2	23.5	10.7	30.4	40.6	31.3	31.6	32.6
	95%	35.1	28.6	31.2	35.9	12.6	35.1	45.0	35.5	35.6	36.6

Table F-10
2014 Average Statistical Summary of the Predictive Errors
Of the Observed and Calculated TDG
At Tailwater TDG Gauges (mm Hg Pressure)

Fixed Monitoring Stations		DWQI	LGNW	LGSW	LMNW	IDSW	GCGW	CHQW	MCPW	JHAW	TDDO	CCIW	WRNO
Number of Obs		1582	3466	3525	3440	3668	654	1753	3672	2921	3452	3660	3660
Average		-7.9	-7.6	5.9	2.5	2.0	-12.6	0.9	7.3	2.8	17.1	1.5	20.3
Standard Deviation		14.6	13.9	11.7	11.7	9.6	15.6	12.2	8.2	9.2	7.9	6.3	11.6
Maximum		232.0	77.5	52.5	52.3	36.0	30.1	61.0	97.6	40.5	67.9	54.9	63.1
Minimum		-63.3	-63.6	-46.2	-49.1	-92.6	-69.6	-44.5	-23.9	-32.7	-9.5	-40.4	-15.1
TDG Predictive Error in % TDG	Percentile												
	5%	-17.4	-37.5	-11.6	-19.3	-11.7	-50.5	-22.1	-4.2	-13.4	4.9	-6.8	2.5
	10%	-15.1	-28.0	-8.0	-14.3	-8.3	-33.9	-16.1	-2.3	-8.8	7.6	-5.0	5.6
	25%	-12.7	-11.9	-2.0	-3.5	-3.2	-16.6	-6.7	1.2	-2.9	12.0	-1.9	11.8
	50%	-8.8	-6.0	4.7	4.4	1.2	-9.9	1.6	6.9	3.5	16.8	1.1	19.6
	75%	-5.8	-0.1	13.2	9.3	6.8	-2.5	10.2	11.7	9.2	21.9	4.2	28.0
	90%	-1.2	5.6	22.2	14.4	13.9	1.3	15.6	18.0	14.1	26.5	10.3	35.7
	95%	2.5	11.0	25.8	19.5	18.6	3.2	17.5	21.9	16.2	29.2	12.4	40.0

2.7 Discussion of the 2014 Statistical Analysis Results

The 2014 statistical analysis resulted in several significant findings and the following is a discussion of them:

Comparison of 2014 Statistical Analysis to Previous Years: The 2014 system-wide statistical analysis compared favorably with the 2005-2014 system-wide statistical analyses, showing the same trends and similar SDs for the TDG gauges. The 2014 statistical analyses showed a system-wide average SD of 1.5% which is identical to the ten-year statistical analysis system-wide average SD of 1.5%.

Lower Granite Tailwater TDG Production Equations: The 2014 seasonal SD of the predictive error at Lower Granite tailwater (1.9%) was higher than the system-wide average SD of 1.5%, but is still acceptable. The Lower Granite tailwater TDG gauge has the highest SD of all 22 gauges evaluated whether it is the ten-year SD or the 2011-2014 period. The 2014 results are consistent with the previous statistical analyses. These findings continue to highlight the potential improvement that could be possible if the TDG production equations at Lower Granite were update, especially in July and August. Since Lower Granite spills to a constant 18 kcfs in July and August which is usually below the spill cap, the SYSTDG model is usually not used to set its spill cap in those months. As a result, there is no pressing need to upgrade the model for those months. This recommendation appeared in the 2009, 2010, 2011, 2012, and 2013 SYSTDG statistical analysis and remains valid, but is not a pressing need.

Lower Monumental Tailwater (LMNW) TDG Production Equations: The 2014 seasonal SD (1.6%) of the predictive error at Lower Monumental tailwater was slightly higher to the ten-year system-wide average SD of 1.5%. The 2014 SD is better than the 2010-2014 period SD which is 1.9% as shown in Table F-6. The 2014 results suggest that the 2009 modification of the TDG production equations continues to be effective to a degree. Since the 2010-2014 period SD of 1.9% is higher than the ten-year system-wide

SD of 1.5%, the recommendation to consider modifying the Lower Monumental TDG production equations found in the 2009, 2010, 2011, 2012, and 2013 SYSTDG statistical analysis remains valid, but it is not a pressing need.

High Predictive Error at John Day Forebay: The John Day forebay gauge had a seasonal average SD of the predictive error of 2.5% in 2014, which was higher than the system-wide ten-year average of 1.5%. It is believed that the main factor causing this high predictive error is the estimate of the amount of degassing that occurs in the McNary to John Day reach. The McNary Dam to John Day Dam reach is the longest river reach (76 miles) in the FCRPS and travel times range from 3.5 to 9.0 days in 2014 (average water year). As weather data is not collected at the reservoirs, but at National Weather Service stations, it is not always representative of weather at the reservoir which can introduce some additional predictive error. The weather station being used is further away from John Day, and if it was located closer it would improve the John Day forebay TDG gauge's predictive errors. Mike Schneider, retired Corps Engineering and Research Development Center engineer and developer of SYSTDG, proposed the idea to use the Hermiston 2NW AgriMet weather station (HERO) instead of The Dalles Municipal Airport weather station (DLS).

This idea was investigated during the development of the 2014 Statistical Analysis of SYSTDG. With the DLS weather station, the John Day forebay had a 2014 seasonal SD of 2.5%. With the HERO weather station, the seasonal SD dropped to 1.9%, so there was a 0.6% improvement in the seasonal SD of the predictive error. As a result, it is recommended that the script for downloading McNary data be modified and that the HERO weather station be used in the 2015 SYSTDG version. The 1.9% SD was included in Table F-7 instead of the 2.5% result from using the DLS weather station.

High Predictive Error at Bonneville Tailwater Gauge - Warrendale: The Bonneville tailwater gauge at Warrendale had a seasonal average SD of the predictive error of 1.7% in 2014 which was above its ten-year average SD of 1.3%. The seasonal average SD of the predictive error at Warrendale was good (SD of 1.5%) until approximately June 19. The monthly average SD of the predictive error for May was only 1%. From June 19 through July, the average SD of the predictive error was two times higher and in August it was three time higher than its ten-year seasonal average SD. This spike in the average SD of the predictive error can be attributed to the fact that flow from the Bonneville Powerhouse 2 Corner Collector (B2CC) outfall, becomes a prominent source of TDG during low flow conditions. According to Laurie Ebner of Portland District, the B2CC outfall flows are estimated to range from 4.2 kcfs to 5.7 kcfs during 2014 and Mike Schneider estimated TDG levels can reach as high as 178%. With low flows, when the Bonneville tailwater elevation drops to 15 feet or less, the B2CC outflow is a distinct plunging trajectory instead of the more horizontal trajectory associated with higher tailwater elevations. This plunging flow then results in higher and persistent TDG production. The 2009, 2011, 2012 and 2013 Appendix Gs contained the recommendation that a TDG field study should be conducted below Bonneville Dam to determine the B2CC outfall's contribution to TDG levels as measured at Warrendale during low and high flows. See Section 5 for a discussion of this recommendation.

Section 3 Highlights of the 2014 Statistical Evaluation

A statistical evaluation of SYSTDG's performance was conducted to assess how well the model estimated %TDG. The SD of the predictive errors that SYSTDG calculated in 2014 compared favorably with the SD of the predictive errors from previous years for most gauges. The following are some of the highlights of the 2014 analysis:

1. The 2014 statistical analysis compared favorably with the 2005-2014 statistical analyses, indicating the same trends for most of the TDG gauges. This multi-year comparison emphasized that the SYSTDG improvements recommended in previous annual statistical analysis are in some instances still valid, but as discuss in various sections of this report, are not pressing needs.

2. The idea of using the Hermiston 2NW AgriMet weather station (HERO) at the John Day Dam instead of The Dalles Municipal Airport weather station (DLS) was investigated during the development of the 2014 Statistical Analysis of SYSTDG. With the DLS weather station, the John Day forebay had a seasonal SD of 2.5%. With the HERO weather station, the seasonal SD of 1.9%, so there was a 0.6% improvement in the seasonal SD of the predictive error. As a result, it is recommended that the scripts for downloading data be modified and that the HERO weather station be used in future SYSTDG version.

Section 4 Causes of SYSTDG Predictive Error

The differences between model estimates and observed %TDG at TDG gauges can be attributed to various sources that can be a challenge to identify. Predictive error documented in this statistical evaluation may represent influences of any of the listed sources below and may not reflect negatively on the SYSTDG model accuracy.

1. The outflow generation and spill values used in these simulations are averaged on an hourly basis. Any operational change occurring within the hour will not be seen because the instantaneous five-minute flow values were averaged with other five-minute values that can be much higher or lower, resulting in an average hourly value. Thus hourly average flow is different than actual flow and can introduce erroneous results in the SYSTDG simulation.

2. The spill pattern used during special operations differed from the approved spill patterns in the fish passage plan. These alternative operations can be attributed to equipment malfunction, spillway gate outages, and dam safety concerns.

3. Limitations in the TDG exchange and production equations for specific operations; background TDG pressures from upstream of the project and changes in TDG pressures observed downstream from the dam.

4. Errors can result from using wrong lag times when attempting to match spill operations from a project and the corresponding TDG measurement downstream. This can be a prominent source of predictive error in the model in estimating TDG at the next downstream forebay.

5. The presence of spatial TDG gradients near a gauge introduced either by thermal patterns or project operations can bias the observed TDG pressure and introduce a prominent difference between the estimated and observed TDG pressure. Thermally induced errors may also occur at forebay gauges where a 1°C increase in temperature above bulk river conditions can result in a 2% to 3% increase in the TDG.

6. Instrument malfunction can cause observed TDG gauge readings to be erroneous resulting in increased predictive error.

7. Sampling biases occur because the SYSTDG model is designed to simulate the average channel TDG production at the gauge transect. Actual TDG saturation at the gauges is a function of flow rate, spill pattern, wind, and other factors resulting in increased predictive error.

Section 5 TDG Field Studies

TDG field studies are periodically scheduled to investigate significant structural or operational changes of the spillway. These studies are designed to support TDG monitoring and management functions; provide updates to TDG gas abatement goals associated with the TDG TMDL; and to update the SYSTDG production equations. During the 2014 spill season, there were no supplemental TDG field studies conducted at Federal projects on the Columbia or Snake rivers.

Several of the previous SYSTDG statistical analyses included recommendations of TDG field studies at five dams. These five TDG field studies are no longer needed because of recent changes that occurred in the spill management or the TDG gauge management. The following is a discussion of the events that removed or reduced the need to perform the studies.

John Day Dam: The 2010, 2011, 2012 and 2013 Appendix G contained the recommendation that a TDG field study should be conducted below John Day Dam to achieve the following three objectives:

1. To better understand the influence of bulk spill through the spillway weirs at bays 18 and 19, with the 50 foot flow deflector in bay 20. The impact of this spill pattern on the entrainment of powerhouse flows into the stilling basin may contribute to modeling errors at downstream stations.

2. To evaluate how much TDG reduction occurs with the 50 foot flow deflector in bay 20. Since its original purpose included reduction of TDG, it is important to know if it performs this function and how much.
3. To determine if the physical design and operation of the 50 foot flow deflector in bay 20 is effective and does it induce more or less powerhouse flow entrainment, since its original purpose included being a flow guidance mechanism, deterring fish from being caught in a powerhouse eddy in the tailrace.

The following is a discussion of each of the objectives:

To better understand the contribution of the bulk spill to modeling errors at downstream stations.
The John Day Dam bulk spill pattern using the 50 foot flow deflector in bay 20 has been entered into SYSTDG and used to predict the TDG production. Since the long flow deflector was operational in March 2010, the five-year SD for John Day tailwater (JHAW) was 1.6% compared to before the installation when it was 1.5%. This is an increase of 0.1% SD, which is not considered significant enough to suggest a TDG field study is needed. This conclusion is further validated by looking at the SDs of the next two downstream gauges, which are The Dalles forebay and The Dalles tailwater. The ten-year average SDs of predictive error for these gauges are 1.2% and 1.1% respectively, which are below the system-wide ten-year average SD of 1.5%, so SYSTDG is accurate in predicting TDG levels at these gauges. So based on these SYSTDG statistical analyses results, the TDG production equations do not need to be improved and a TDG field study isn't needed for this objective.

To evaluate how much total dissolved gas reduction occurs with the 50 foot flow deflector.
SYSTDG is able to predict the TDG levels from the John Day Dam as they arrive at the next downstream gauges which are The Dalles forebay and tailwater gauges. The ten-year average SDs of predictive error for these gauges are 1.2% and 1.1% respectively, which are below the system-wide ten-year average SD of 1.5%, so SYSTDG is accurate in predicting TDG levels at these gauges. So based on these results from the SYSTDG statistical analyses, SYSTDG accurately predicts the amount of TDG reduction that is occurring as a result of the 50 foot flow deflector performance. Therefore a TDG field study is not needed for this objective.

Does the design of the 50 foot flow deflector in bay 20 induce more or less powerhouse flow entrainment?
In order to determine whether the 50 foot flow deflector reduces powerhouse flow entrainment, additional field measurements involving transect sampling for dissolved gasses are necessary. This information is needed to determine whether the long 50 foot flow deflector design and operation is more effective than shorter 12.5 foot ones and does it induce more or less powerhouse flow entrainment. This recommendation and the study continue to apply for this objective, especially if the 50 foot flow deflector design is considered for other dams. [1] Currently, a long 50 foot flow deflector is not being

[1] A TDG field study was performed in 2010, but the data has not been evaluated.

considered at another dam, so there is no pressing need for a TDG study for this objective.

Grand Coulee Dam: The 2010, 2011, 2012 and 2013 Appendix G contained the recommendation that a TDG field study should be conducted below Grand Coulee to better refine the TDG production and exchange equations in SYSTDG. Updated TDG production equations were considered needed to better differentiate spill through the outlet tubes compared to the drumgates and to validate the TDG production of the powerhouse flows because of consistent differences between the TDG levels in the forebay and tailwater during powerhouse releases. As discussed in Section 2.3, the 2011 modified GCL TDG production equations significantly improved the SD so that a field study is no longer needed. If spilling through the outlet tubes became a regular event during spill season and the tailwater gauge SD increased to 2.5% or higher, which is unacceptable, than a field study may be needed.

Chief Joseph Dam: The 2011, 2012 and 2013 Appendix Gs contained the recommendation that a TDG field study should be conducted below Chief Joseph to investigate the TDG production and exchange as a function of spillway flows and patterns so that the equations in SYSTDG can be refined. This recommendation was linked to a proposed TDG study designed for a limited spill condition when spill's primary objective is to strip TDG from the river. Since the Corps has been developing various Chief Joseph spill management approaches for different river conditions, this study is no longer needed. This conclusion is confirmed by the SYSTDG five-year SD of the predictive error of 1.4% for Chief Joseph tailwater, which is less than the ten-year system-wide SD of 1.5%, showing that SYSTDG accurately predicts the TDG levels at Chief Joseph tailwater.

Bonneville Dam: The 2009, 2011, 2012 and 2013 Appendix Gs contained the recommendation that a TDG field study should be conducted below Bonneville Dam to determine the B2CC outfall's contribution to TDG levels as measured at Warrendale during low and high flows. The B2CC outfall can contribute significantly to the TDG loading below Bonneville Dam during low flow and low tailwater conditions that typically occur in July and August. Additionally, the TDG exchange at Warrendale during higher flows remains difficult to model and is an area for further model development. Since the Warrendale gauge is not used to set daily spill caps unless the Cascade Island gauge is malfunctioning[2], there shouldn't be a need to use the Warrendale TDG gauge for FOP spill. In this case, it is an option to disconnect the Warrendale gauge in March as was done during previous years and this issue disappears. This recommendation and the study is considered a low priority or potentially no longer needed for several reasons, which are:

- The B2CC TDG levels do not affect the readings at the Cascade Island TDG gauge, which is used for spill management.
- The B2CC TDG levels do affect the readings at the Warrendale TDG gauge during the summer, which is not used for spill management, unless the Cascade Island gauge quits working.

[2] Portland District has upgraded and reinforced the instrument conduits of the Cascade Island gauge in 2014.

- The Cascade Island gauge is expected to be reliable in the future and to continuing working. In 2014, Portland District fortified the physical design of the Cascade Island gauge so that it should be able to withstand high flows.
- Bonneville spill cap changes during the summer are expected to be rarely needed because of two changes that occurred in 2013 and 2014: the Camas TDG gauge is no longer used for spill management and the change in Bonneville summer spill operations to 85 kcfs during the day and 121 kcfs at night. Therefore, the need to model TDG levels below Bonneville during the summer using SYSTDG is minimal, if at all.

Dworshak Dam: The 2010, 2011, 2012 and 2013 Appendix Gs contained the recommendation that a TDG field study should be conducted below Dworshak Dam to confirm the TDG production and exchange equations that are currently used in the model. These equations estimated the TDG levels in regulating outlets and spillway flows at Dworshak Dam from well mixed water conditions at the DWQI tailwater TDG gauge. Direct measurements of the TDG levels in spill flows should be collected to confirm these equations. A review of the annual SDs for the Dworshak tailwater shows that it varies from slightly above or below the ten-year system-wide SD of the predictive error. In some years, SYSTDG predicts the TDG levels better than other years, depending on the spill operations, which is why this recommendation appears in several years Appendix Gs. But the ten-year SD of the predictive error for Dworshak tailwater of 1.3 % is excellent and is less than the ten-year system-wide SDs of 1.5%. This shows that SYSTDG can accurately predicts the TDG levels at Dworshak most of the time. Therefore, a field study is low priority, if at all.

Section 6 Improvements Made to SYSTDG in 2014

During 2014, the following improvements were made to the SYSTDG model.

1. The link between the coefficients of the weather station and the Little Goose Dam TDG production equations were corrected.

2. SYSTDG was converted to pull data the current year's data from the CWMS database instead of from two Access databases that was populated from various internet websites. A suite of 22 queries were established that pulls data from CWMS and put it into text files that SYSTDG downloads into the model. This improvement was initiated in 2013 and completed in 2014.

3. The Washington method of calculating 12 hour average %TDG based on 12 consecutive hours was added to SYSTDG, as recommended in the 2009 Appendix G.

4. The feature of entering spill patterns into SYSTDG was added to Chief Joseph Dam, as recommended in the 2013 Appendix G.

5. RCC Water Quality requested a revised Lower Monumental spill pattern with gate settings for a spill rates as low as 6 kcfs and it was used during the 2014 spill season, as recommended in the 2013 Appendix G.

6. RCC Water Quality requested an expanded McNary spill pattern that covers high-flow spillway discharges (up to 300 kcfs) for the 2015 spill season, as recommended in the 2013 Appendix G.

7. The workbooks and equations used to generate the statistical analysis used to generate this appendix were added to SYSTDG.

Section 7 SYSTDG Improvements Recommended for 2015

The improvements and maintenance activities to the SYSTDG model that are recommended for 2015 include some of those that have been identified in previous year's analyses.

1. Recommend an upgrade of SYSTDG to pull any year's data: In order to be able to model any water year, it is necessary to be able to pull any year's data into SYSTDG. The SYSTDG queries that provide the data for downloading were modified to perform this task. We need SYSTDG to be modified to be able to import that data for any year. We think this involves modification of the URLs options listed in SYSTDG so the model can select the year to be modeled.

2. Recommend that the McNary script for downloading data be modified so that the HERO weather station will be used in future SYSTDG versions.

3. Recommend that there is an investigation of using different AgriMet or NOAA weather stations for those forebay TDG gauges that have elevated SD. A 0.6% reduction in the McNary forebay 2014 SD suggest that a change of the weather station could resulted in improvements in other forebay TDG gauges' SD. Since SYSTDG uses a hydrological routing procedure that involves surface aeration exchange with dispersion to calculate/estimate %TDG level at the next downstream forebay, the effects of the wind speed is instrumental in these forebay %TDG calculations/estimates. Wind speed is the main parameter used in SYSTDG from these weather stations and plays a major role in degassing rate. Since the forebay gauges at Little Goose, Lower Monumental and McNary dams have a ten-year SD of 1.7 to 2.0%, their weather stations are potential candidates for consideration. The Little Goose forebay gauge uses the Lake Bryan-Rice Bar, WA (LBRW) weather station. The Lower Monumental forebay gauge uses the Tri-Cities Airport, Pasco, WA (PSCW) weather station. Since the Hermiston 2NW AgriMet (HERO) weather station will be used for the McNary forebay gauge beginning in 2015, there is no need to investigate another weather station, until several years of using HERO shows that it needs to be reconsidered.

4. Since the Lower Granite tailwater and Warrendale TDG gauges SDs are influenced by high predictive errors in July and August, and the SYSTDG model is typically not used after July 15 due to low flows, it would be a good idea to investigate what would happen to the SDs for all gauges if the "SYSTDG functional" period for a statistical evaluation is modified. Therefore, it is recommended that the "SYSTDG functional" period when a statistical evaluation is most appropriate is determined. Should the functional period be in terms of months (April 1 – July 15) or in terms of flows? The 2005-2014 statistical analyses were performed for April through August, which seems inappropriate since SYSTDG is typically used during average and high flow periods in April through July 15. This investigation should evaluate what the individual gauge and system-wide SD is for different flows and different time periods and the most appropriate one recommended for future SYSTDG analyses.